Vehicle Health Maintenance and Analysis Using Advanced Statistical Methods and Adaptive Techniques

Anthony R. Kelley/EB23
205–544–7646
E-mail: anthony.kelley@msfc.nasa.gov

The Center Director's Discretionary Fund proposal, Vehicle Health Maintenance and Analysis Using Advanced Statistical Methods and Adaptive Techniques, was funded in October 1995 for 2 years. The primary objective was to develop vehicle health monitoring algorithms using statistical methods, genetic algorithms, neural networks, expert systems, and fuzzy logic. These methods have been applied to several different kinds of problems with successful results.

The project discussed is detection of high-pressure fuel pump turbine blade breakage in real-time during the Space Shuttle Main Engine (SSME) ground tests. During two ground test firings, turbine blades have broken without the turbine exceeding the redline shut-down values. The first time this failure occurred, a technician manually shut down the engine after seeing an abnormal plume. The second time, redlines shut down the engine much later than the actual blade breaks occurred. Blade breakage can be located in post-test analysis, but cannot be monitored in real-time at present. This type of failure can destroy a high-pressure fuel pump valued at approximately $2 to 4 million and/or the engine valued at $40 to 60 million. If the blade breakage can be detected accurately, then the probability of extensive engine damage may be reduced and may reduce engine development costs.

To detect turbine blade breaks, an analysis technique was developed using algorithms in the following form: If A > B, then blades are breaking, where A and B can be averages, differences, normalizations, constants, transforms, or other rules joined by "and" statements. The inequality could be less than or equal to B or greater than B in all the evaluations. There are no constraints to how many relationships are evaluated. For example, a rule could be: If A > B and C = D and A <= E, then blades are breaking, where A, B, C, D, and E are values as defined above.

The analysis technique described above was applied to the data base from the first SSME failure and detected all five blade breaks with no false indications. Next, the technique was applied to other normal tests and one other test where turbine blades broke. On the larger data base, the rule detected the known blade breaks, but gave six false positive signals. Due to the desire to have zero good engine test terminations, the causes of the false signals generated by the analysis technique were carefully reviewed. As a result of the review, a simple modification eliminated all the false positive signals. The analysis technique then detected all six (100 percent) blade breaks out of 35 test runs and gave no false positive indications (0 percent) of failure. The 35 tests correspond to approximately 35,000 test samples in which the analysis technique never failed. The analysis technique form and values may require slight modification for SSME hardware changes, but should maintain high-fidelity results similar to those indicated above.

If the proposed analysis technique provides zero or near-zero false indications in all available test data, then the algorithm could be included in the ground test monitoring system and possibly in the engine controller for real-time vehicle health monitoring. Each detected blade failure could save a turbopump ($2 to 4 million) or an engine ($40 to 60 million). The same analysis techniques should be applicable to anomaly detection in other types of turbines, engines, and machinery used in industry.

Future work in this area will concentrate on using artificial intelligence to create sensor redundancy and sensor validation on engines, developing an adaptive health monitoring system that responds to small hardware changes, and chaining several small expert systems (as described above) together to create a real time diagnostic system for the SSME. Additionally, the techniques will be applied to power plant turbine generators for detection of broken turbine blades, which should save money and shorten downtimes.

Sponsor: Center Director's Discretionary Fund

Biographical Sketch: Anthony Kelley has been an electrical engineer with MSFC since 1985. He has a bachelor of science in electrical engineering from the University of Alabama in Huntsville and a master of engineering, operations research and industrial engineering, from Cornell University. He is currently designing and building data acquisition and control systems for various instruments flown on satellites, sounding rockets, zero-g planes, and the shuttle.